A SHORT EXPERIMENT TO MEASURE OCEAN RADAR BACKSCATTER AND RELATE IT TO SLOPES

[Continuation of *Interaction of Ocean Waves and Radar Signals*, N00014-89-J-3221]

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Award #: N00014-97-1-0677

LONG-TERM GOALS

The long-term goals of The University of Kansas Center for Research project "Interaction of Ocean Waves and Radar Signals" are to improve and add new understanding of radar ocean imaging and to improve understanding of interactions with the longer waves of the small waves that represent the wind input to the sea.

SCIENTIFIC OBJECTIVES

Understanding modulation of radar signals by ocean waves is important for improving satellite synthetic aperture radar (SAR) operation for global ocean study. This should permit better understanding of wave imaging, as well as of imaging of ocean features, such as fronts and current boundaries. It is also important for aircraft imaging of the ocean.

Understanding the nature of large-scale short-time excursions of radar signals, known as sea spikes, is important both to applications of radar observing targets on the sea and to understanding the nature of the nonlinear processes on the ocean.

Understanding radar scatter and understanding small-scale waves on the sea should lead to improved models of oceanic processes. In this connection, we are concentrating particularly on nonlinear phenomena such as wave breaking.

A further objective is to refine the vector slope gauge (VSG) as a tool for oceanographers.

APPROACH

The SAXON experiment was the first to use the unique VSG, and analyzing the limited data was a lengthy process. Accordingly, we found that more experiments using this new tool are necessary. The VSG is a multipurpose radar designed to determine simultaneously: the slope vector on the ocean surface within a footprint about 2 m diameter and the modulation of the radar signal compared with the instantaneous slope and wave height.

Note that this is different from unmodulated radar scatterometers, which depend on Doppler frequency measurements and linearity assumptions to relate the signal to the wave height and slope. It also differs from range-measuring scatterometers, which use a single beam to measure the range and therefore wave height, but cannot directly measure the slope.

To perform the new experiments, we first had to modify the VSG, using knowledge gained during the SAXON experiments and a recent thorough study of its limitations and capabilities. In late 1995, we conducted an experiment at Duck Pier, NC, to test the modified instrument. Further

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1997**	2. REPORT TYPE	3. DATES COVERED **00-00-1997 to 00-00-1997**

4. TITLE AND SUBTITLE **A Short Experiment to Measure Ocean Radar Backscatter and Relate It to Slopes**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Radar Systems and Remote Sensing Laboratory,2291 Irving Hill Road,Lawrence,KS,66045**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

modifications are now complete as we prepare for a second experiment at Duck Pier. These new changes will permit higher sampling rates and, by using a fully digital data-handling system, allow measurement of Doppler shifts as well as range and slope.

Some of the tasks involved in data analysis when the VSG is used in full-scale experiments are:

1. To determine the relation between the backscattered radar signal and the ocean surface characteristics; e.g., surface elevation and slope spectra, two-dimensional directional wave spectrum, hydrodynamic modulation of the ripples by long gravity waves, orbital velocities.
2. To study radar sea-spike phenomena at moderate angles of incidence and their relation to ocean surface characteristics. Clearly, they are related to nonlinear characteristics of the surface.

Tasks carried out to prepare for and conduct the new experiments included:

1. Designing, rebuilding, and testing an improved version of the VSG/35-GHz scatterometer, which also has improved calibration, all-digital data handling, and Doppler-measurement capability.
2. Testing the VSG radar system as an ocean directional spectrum analyzer. An experiment at Duck Pier, NC, will take place in January 1998.
3. Upon completion of the test of the new system, we will propose using the improved VSG to obtain new information about the sea. This will involve experiments from an ocean platform. We hope to conduct these tests jointly with other institutions. A proposal combining these measurements with a study of responses needed for understanding spotlight SAR performance is being developed with APL/JHU.

Data and System Analysis

We earlier developed a method to use slopes from the VSG to separate the hydrodynamic and tilt modulation of the received radar signal based on a nonlinear, multiplicative, relation between the two modulations. The VSG provides information on the slopes. We then calculate the tilt modulation from the slopes, using accepted theoretical methods. Since the tilt and hydrodynamic modulations combine in a product, one can use the known tilt modulation to extract the hydrodynamic modulation. The method was applied to sample SAXON data, but accurate use must await further experiments.

A new approach we developed using autoregressive (AR) methods permits a new view of the modulation of the radar signal vs. position on the wave. Using it we obtain the average radar return vs. the phase of the long wave. The distance from the crest for a given cycle is different from that for other cycles. This distance is converted into phase for the specific cycle, and the radar signal at that point is recorded as being at the correct phase.

When this is complete for all cycles in the data, the signals for each phase are averaged. Note that this method does not require that one treat the frequency components in the wave spectrum separately. It applies to all waves. This new approach can lead to significant increases in understanding radar signals for both simple and complicated wave situations. We prepared a paper illustrating the application of this method to SAXON and 1995 Duck Pier data.

Details regarding this new method were provided in last year's ONR report and in more detail in the journal paper being submitted.

Systems and New Experiments

The Vector Slope Gauge (VSG) is a 35-GHz range-measuring radar scatterometer with a three-beam antenna. At SAXON-FPN the three beams, approximately 1.5• wide, were switched sequentially at 1/30-s intervals to illuminate three adjacent spots of the sea surface. In the 1995 Duck Pier experiment, the switching rate increased to 300/s. The radar measures the ranges to the three footprints, which allows determination of the average surface elevation for each footprint and a first-order approximation of the two-dimensional wave slope. At an antenna height of 20 m and 45• angle of incidence, the footprint sizes are close to 75 by 105 cm and the length of the waves for which we can measure 2-D slopes safely is between 12-15 m and 160 m. Therefore for deep water the reliable wave frequency range of the VSG for slope measurement is from 0.1 Hz to 0.35 Hz. Use of a single beam permits measurement of scattering and modulation for somewhat higher frequencies because the single footprint is smaller than that of the three-beam complex.

During FY97, we nearly completed the rebuilding of the VSG. Previously, range measurement used an analog frequency-to-voltage converter, and the voltage output was digitized. With the new system, the 200-kHz intermediate frequency (IF) is digitized, and measurement of the range frequency is by digital filtering. The frequency modulation uses a triangular waveform with successive up sweeps and down sweeps. The digital processing permits separate measurement of the range frequency on the up and down sweeps. The average of these frequencies gives the range and their difference gives the Doppler shift.

The sampling rate for the new system is about 3000 samples/s. This permits, in principle, a 1-kHz sampling of the slope. In practice it will be necessary to average several samples to obtain adequate precision, so the actual output rate will be less. Simulations to determine the best tradeoff between output rates and precision are underway.

The VSG can be used together with other scatterometers to relate the scattering from the ocean surface to both slope and height of the sea. We can then separate tilt and hydrodynamic modulations. This should allow resolving of significant questions that remain about the basis for oceanic modulation of the radar backscatter. Our plans call for experiments using the VSG together with the C-/Ku-band systems in the open sea.

We propose to conduct an experiment at an offshore oil platform in the Gulf of Mexico. In this we have been cooperating with JHU-APL and Exxon. We identified an Exxon production platform that has two structures connected by a bridge. For one experiment, the VSG would be located on the bridge, looking vertically, and the other scatterometers would be far enough away so that they could observe the same spot on the surface as the VSG, but at, say, 45• angles of incidence. For Ka-band scattering studies, the VSG will be operated off vertical, with other scatterometers viewing the same spot. For a spotlight SAR experiment, JHU-APL will provide CW scatterometers to mount along the bridge allowing multiple simultaneous azimuthal looks at the same spot on the surface.

WORK COMPLETED

1. Analysis of SAXON-FPN modulations and comparison with those from UWASH-APL (completed on previous contract).
2. Analysis of SAXON-FPN sea-spike data, including use of the AR method (completed on previous contract).
3. Comparison of SAXON-FPN directional histograms and comparison with pitch-and-roll buoy data (completed on previous contract).
4. Analysis of SAXON-FPN radar wind response (completed on previous contract).
5. Analysis of VSG error sources (completed on previous contract).
6. Exact location of VSG beam positions (completed on previous contract).
7. Rebuilding VSG with faster switching and digital range processing.
8. Preparing software for use with new system (partially completed).
9. Conduct first Duck Pier test of radars (completed on previous contract).
10. Analysis of Duck Pier data from first experiment (completed on previous contract).
11. Search for suitable oil production platform for new experiment (completed on previous contract).
12. Preparation of a paper on the sea-spike analysis for SAXON-FPN.
13. Preparation of a paper on the AR approach, using data from the Duck Pier experiment.
14. Preparation for second Duck Pier experiment, including design of new pier mounting structure.

RESULTS/CONCLUSIONS

A new method using AR techniques allows measuring both modulation and sea-spike characteristics vs. position (phase) on individual cycles of long ocean waves. This is particularly important for complex wave systems where individual crest-to-crest distances may vary significantly. We applied this technique to 1995 Duck Pier data, giving new clues to the nature of the modulation. The usual spectral approach is difficult to interpret for crossing wave trains and for look directions other than upwind-upwave or downwind-downwave. The new approach has no such limitations. A paper on the subject has been prepared.

A method to use slopes from the VSG to separate the hydrodynamic and tilt modulation of the received radar signal was tested on SAXON-FPN data and awaits new data from the revised VSG for full application.

Comparison of height and Doppler-based modulation phases for SAXON-FPN data show that they differ, with Doppler phases near 60• and height phases near 90• . Interestingly, at Duck Pier we found 30• to 50• , but this was for downwind observations. The latest version of the VSG will allow finding differences between all three approaches with the same data. Explanation of this difference will lead to better understanding of radar-ocean interaction.

The AR method permitted us to observe that spikes are uniformly distributed over the long waves, but spike energy has peaks on both the front and back faces of the long waves.

The VSG has a new all-digital data-processing system that is nearly complete. A preliminary test of the new data system and faster sampling will occur in January 1998, at Duck, NC. We hope to use the modified systems for an experiment from an oil production platform. First, however, we must perform another experiment at Duck Pier to test the digital system and more rapid sampling.

IMPACT FOR SCIENCE

The new AR approach to examining radar signals from individual cycles of underlying ocean waves will permit an entirely different kind of understanding of modulation and spike distribution. We believe this approach will have wide application.

Theories for hydrodynamic modulation of the ripples and therefore the radar signal are contradictory. Our method for separating tilt and hydrodynamic modulations using VSG data should help resolve these theoretical discrepancies. These may also lead to improved prediction and understanding of SAR images of the sea.

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